Predicting Stellar Angular Sizes

Gerard van Belle

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

193rd Meeting of the American Astronomical Society

5-9 January 1999, Austin, TX

Introduction

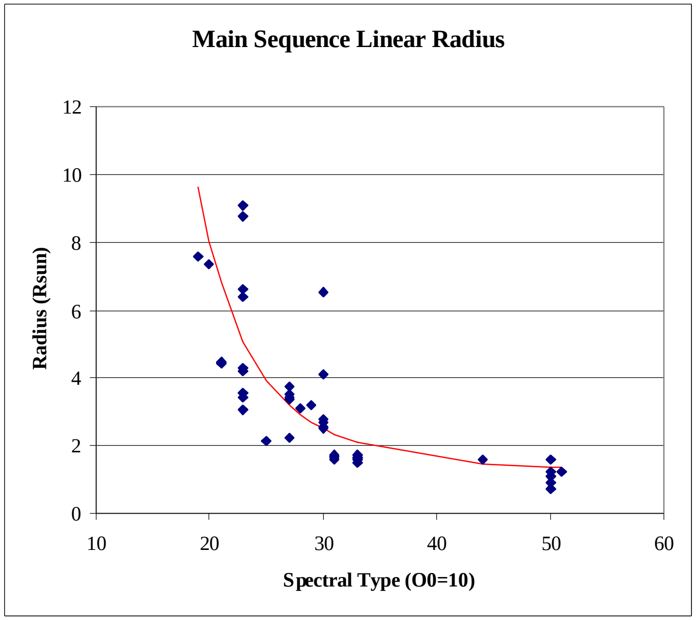
- Often need angular sizes to calibrate instrument response
- Approaches
  - Linear radius
  - Blackbody fitting
  - $\theta_{V=0}$ apparent size
- Compare predictions of various methods with measured values

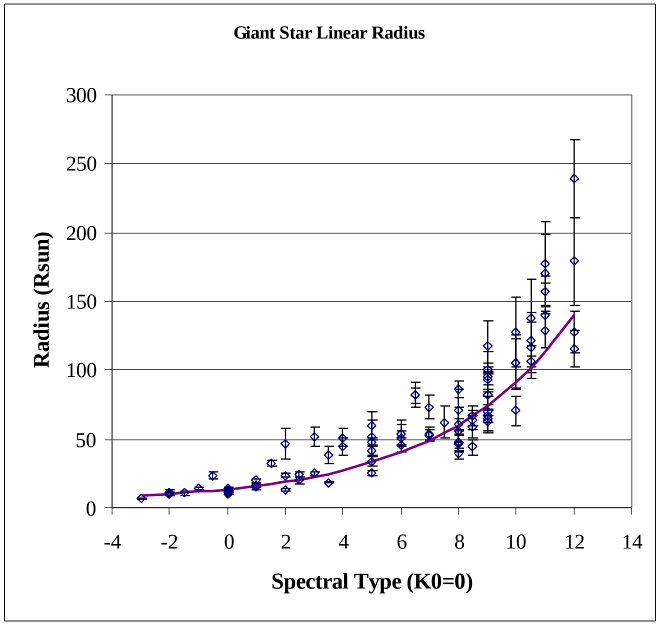
Abstract

Predicting the angular sizes of stellar sources is a tool of particular utility for astronomical interferometry in the optical and infrared. Methods for estimating angular sizes of main sequence and giant stars are presented, including: linear radius as a function of spectral type or V-K color, blackbody estimators, and m_V=0 apparent angular size as a function of V-K color. The latter method is an empirically determined relationship that draws upon existing measurements of stellar angular diameters from both interferometry and lunar occultations. Deviations of more evolved objects such as Mira variables and carbon stars from that relationship are also presented. These angular sizes are incorporated in visibility normalizations, and the sources of uncertainty in visibility normalization for interferometric data are examined in detail. Acceptable levels of uncertainty are derived from rigorously determined errors associated with each method. These angular size determinations are equally valid for other applications as well, such as lunar occultations and speckle imaging.

Linear Radius by Spectral Type

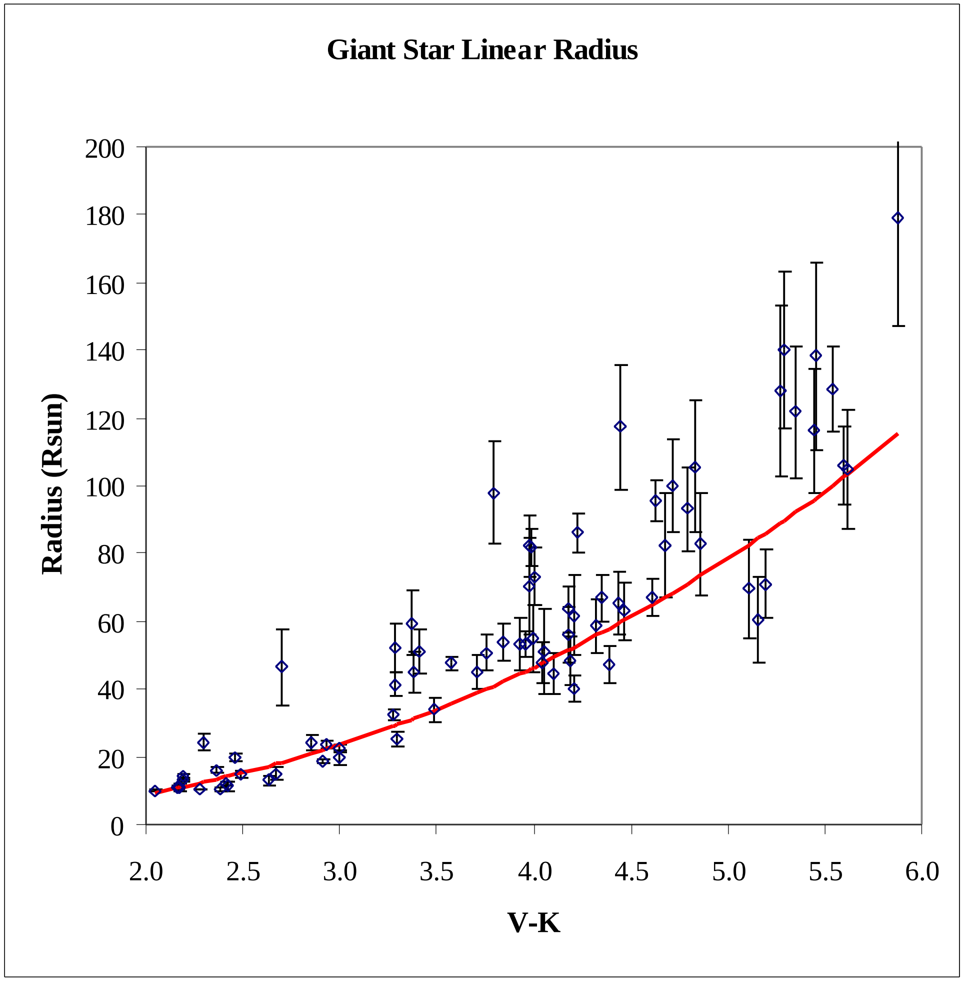
- Main sequence stars
  - $R = 1.21 \pm 0.22 + 1.47 \pm 0.38 \times 10^6 \times SP^{-4.17 \pm 0.07}\ R_{SUN}$ [O0=10]
- Giant stars
  - $R = 4.04 \pm 1.40 + 9.58 \pm 0.84 \times 10^{0.096 \pm 0.006 \times SP}\ R_{SUN}$ [K0=0]





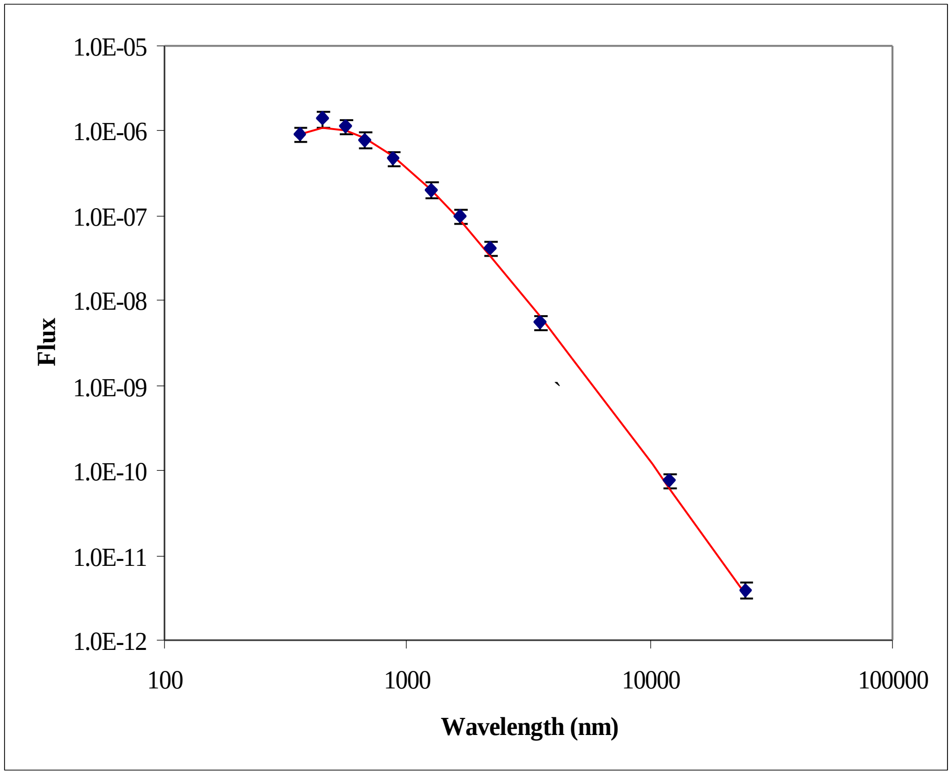
Linear Radius by V-K Color

- Giant stars
  - $R = 1.76 \pm 0.13 \times (V\text{-}K)^{2.36 \pm 0.06}\, R_{SUN}$
- No obvious relationship for main sequence stars
  - V-K color on Rayleigh-Jeans tail for LCV stars



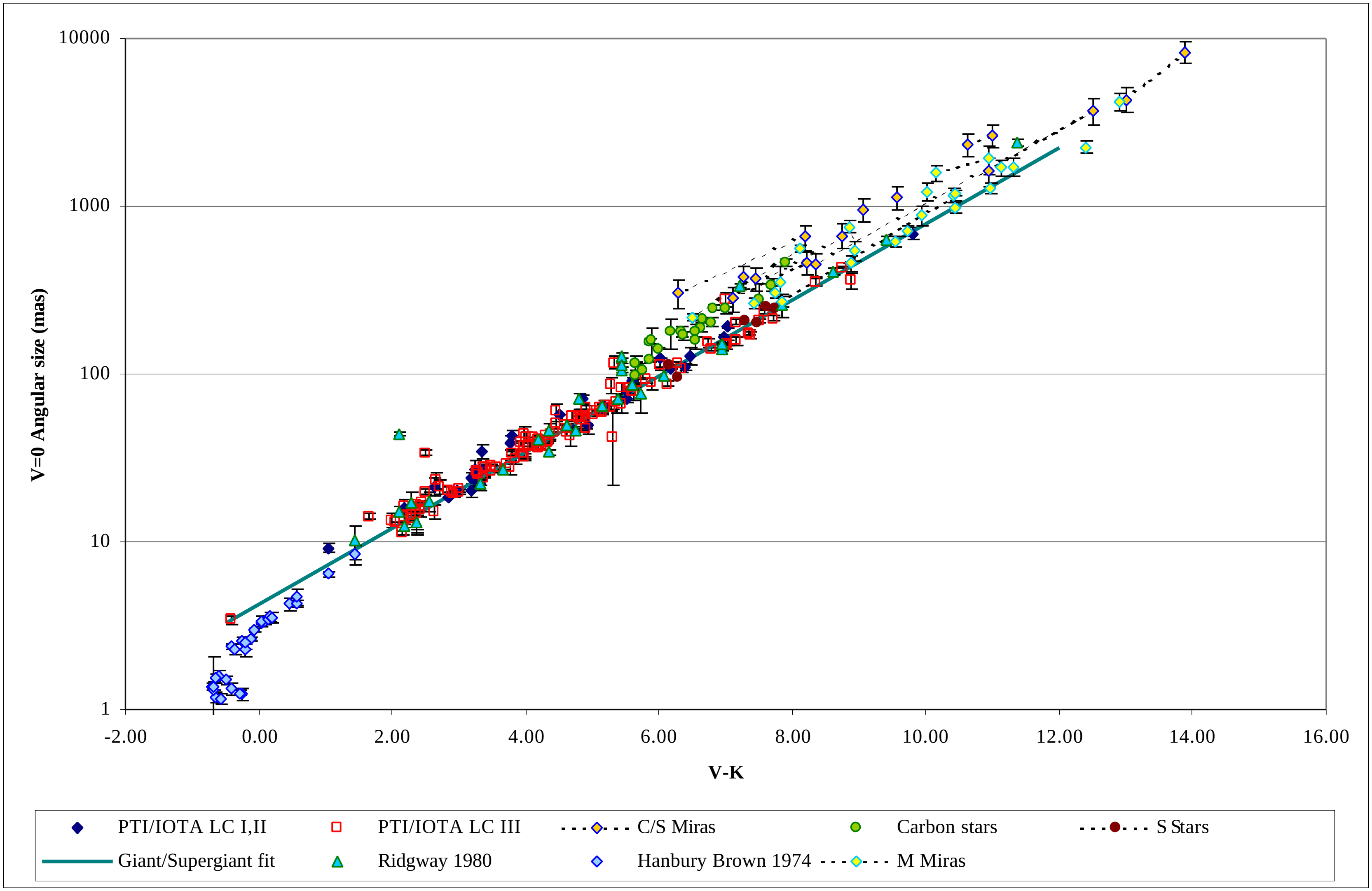
Bolometric Flux Fitting

- Stars are not perfect blackbody radiators
- Some come close
  - F,G,K main sequence and giant stars
- Hot stars - Balmer discontinuity deviates curve from BBR
  - T > 7,000K



- Cool stars - Angular size gets underestimated
  - T < 3,500K
- Overall, accurate but difficult for the appropriate stars

$q_{V=0}$ Apparent Angular Size



$q_{V=0}$ Apparent Angular Size (II)

- Can scale angular size to m_V=0 apparent angular size
  - $q_{V=0} = q \times 10^{V/5}$
- Robust relationship common to LC I, II, III stars
  - $q_{V=0} = 10^{0.682\pm0.014 + 0.222\pm0.003 * (V-K)}$
  - valid for all the luminosity classes
- Slight shift in intercept for evolved sources
  - $q_{V=0} = 10^{0.801\pm0.039 + 0.220\pm.005 * (V-K)}$
  - no change in slope, however
- LC V stars
  - $q_{V=0} = 10^{0.503\pm0.027 + 0.328\pm0.166 * (V-K)}$
  - severely limited by lack of data points - only valid over range -0.5 < V-K < +0.5

Comparison of the Methods

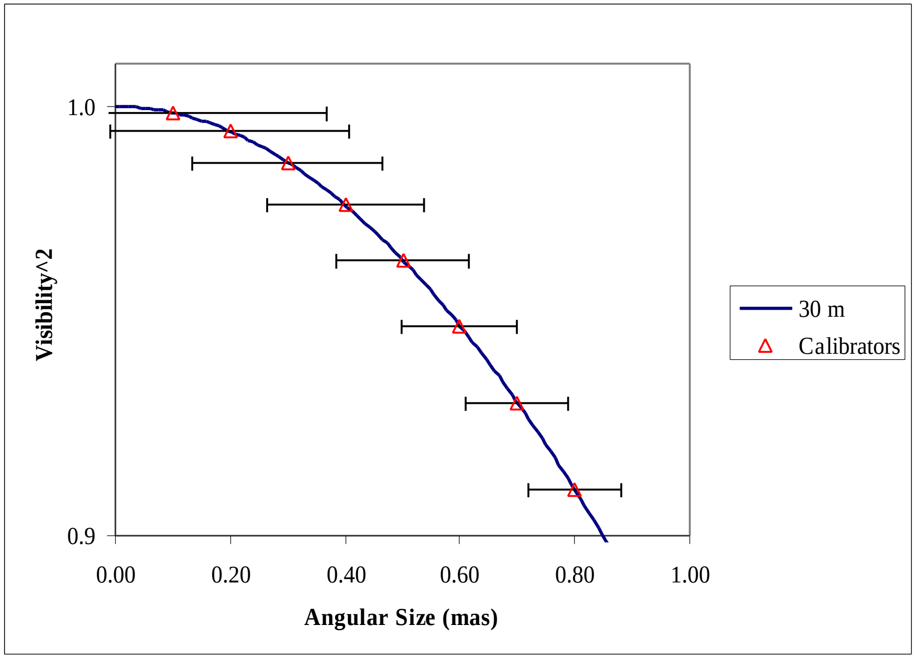
- Analysis of spread of predictions vs. previously measured values
- Best methods:
  - BBR fit
  - $q_{V=0}$ angular size vs. V-K color
- $q_{V=0}$ approach is simplest

Method	1 sigma	2 sigma	3 sigma	Notes
Linear Radius by Spectral Type				
Main Sequence Stars	25	42	60	
Giant Stars	22	37	52	
Linear Radius by V-K Color				
Giant Stars	22	36	51	
Angular Size by BBR Fit				
Main Sequence Stars	13	35	57	*
Giant, Supergiant Stars	18	35	52	
FG	8	16	23	*
K	10	17	25	*
M	21	45	69	
V=0 Angular Size by V-K Color				
Main Sequence Stars	2	4	6	*, Limited V-K range
Giant, Supergiant Stars	10	17	25	*
Variable Stars	21	38	54	

Comparison of the various methods for obtaining angular size. An asterisk '*' denotes the preferred methods for predicting calibrator angular sizes.

Unresolved Source Selection

- Often need predicted angular sizes to calibrate interferometer data
- Smaller stars can have larger angular size errors



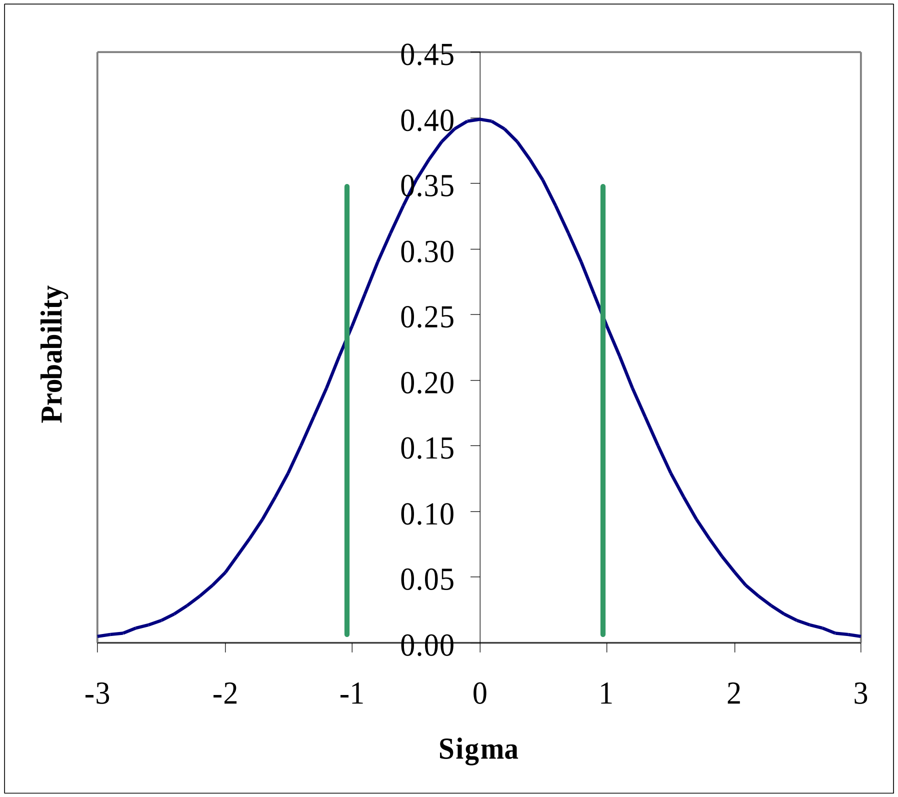
?$_{ESTIMATED}$	Visibility^2
0.100 +- 0.268	0.999 +- 0.018
0.200 +- 0.207	0.994 +- 0.018
0.300 +- 0.165	0.987 +- 0.018
0.400 +- 0.136	0.977 +- 0.018
0.500 +- 0.116	0.964 +- 0.018
0.600 +- 0.101	0.949 +- 0.018
0.700 +- 0.089	0.931 +- 0.018
0.800 +- 0.081	0.911 +- 0.018

Error Bars and Confidence Levels

- Gaussian errors lead to confidence levels

Sigma	Confidence Level
1	68%
2	95%
3	99%

- Can choose an error bar based upon the necessary confidence level



Palomar Testbed Interferometer

- Properties
  - 110m baseline
  - H, K band operation
  - 1-4 mas resolution
  - 100 μas dual-star astrometric resolution
  - Prototype for the Keck Interferometer
- Recent publications
  - Upper mass limit for 51 Peg (Boden *et al.*), stellar angular diameters (van Belle *et al.*), FU Ori resolved (Malbet *et al.*), orbit of RS CVn star TZ Tri (Koresko *et al.*), orbit of spectroscopic binary ι Peg (Boden *et al.*), instrument description (Colavita *et al.*), fringe visibility estimators (Colavita)

References

- K Band angular sizes
  - Preferred source for cool stars - giants, supergiants, Miras, carbon stars
  - Kitt Peak (Ridgway *et al.*), TIRGO (Richichi *et al.*), IOTA (Dyck *et al.*, van Belle *et al.*, Perrin *et al.*), PTI (van Belle *et al.*)
- V Band angular sizes
  - More appropriate for the hotter stars
  - Narrabri Intensity Interferometer (Hanbury Brown *et al.*), Mark III (Mozurkewich *et al.*), COAST (Haniff *et al.*)